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Chapter 29

AN INNOVATIVE APPROACH TO PROTECTING A MUNICIPAL SUPPLY WELL – AIR/OZONE SPARGE CURTAIN RESULTS

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Abstract: Petroleum contamination from a gasoline station threatened a nearby municipal supply well. MTBE was present in groundwater up to 30,000 µg/L in the first encountered groundwater aquifer—30 to 45 feet bgs. The muni well is 200 feet downgradient of the source area, and monitoring indicated MTBE had migrated off site towards the well, necessitating remedial action. An innovative remediation system was designed, combining aggressive source area treatment using soil vapor extraction and a downgradient in situ treatment barrier at the property boundary.

The downgradient in situ treatment barrier includes air/ozone sparge wells placed between the source area and the muni well to reduce/destroy MTBE and other residual gasoline-range organic contamination. The barrier—a sparge curtain—comprises dual-completion air/ozone sparge points co-located in the aquifer's deeper and shallow portions.

Pilot test results showed MTBE concentrations were 780 µg/L initially, 50 µg/L after 8 days, and 1.5 µg/L after 35 days, and tertiary compounds were not generated. A downhole video camera recorded the intercept on the monitoring well from the sparge points. Contaminant concentrations in downgradient wells have shown further improvement, and the system continues to protect the well. Site closure is expected following further monitoring.

Key words: Muni well protection, air/ozone sparging, downhole video camera, remediation, innovative remedial process, MTBE

1. INTRODUCTION

Releases of petroleum contaminants from a retail gasoline station in a medium-sized California Central Valley town threatened a municipal supply well (muni well) immediately adjacent to the station. Methyl *tert*-butyl ether (MTBE) was present in groundwater concentrations up to 30,000 micrograms per liter (µg/L) in the first encountered groundwater aquifer, between 30 to 45 feet below ground surface (bgs). The muni well is open-bottomed at 260 feet bgs and completed to a depth of 290 feet bgs, and is located approximately 200 feet downgradient from the source area. The project team's concern was the potential for MTBE to be pulled toward the muni well's screened interval in the deeper zone, thereby compounding the complexity of site restoration. Subsequent quarterly groundwater monitoring results indicated that MTBE had been migrating off site and that remedial action was required to protect the downgradient well.

In response, the project team designed an innovative remediation system for this site, comprising aggressive source area treatment with soil vapor extraction (SVE) for vadose zone contamination and a downgradient *in situ* treatment barrier at the property boundary. The comprehensive remediation process combines an *in situ* air/ozone sparging system with the SVE system. The *in situ* treatment barrier includes air/ozone sparge wells placed downgradient of the source area and upgradient of the muni well. The system is designed to reduce/destroy the concentrations of MTBE and other residual

gasoline-range organic (GRO) compounds. The perimeter *in situ* treatment barrier is referred to as a sparge curtain, comprising a line of air/ozone sparge points with overlapping radii of influence (ROIs) co-located in the deeper and shallow portions of the first encountered aquifer. During preparation of the Corrective Action Plan (CAP) and the permitting process, the local County Lead Enforcement Agency (LEA) expressed their concern over generating potentially harmful tertiary compounds as the result of the potential oxidation reactions of ozone and aquifer materials. URS developed a pilot test protocol for this process and agreed to share test results with the LEA prior to exercising full system operation. These results showed an initial "Time 0" MTBE concentration of 780 μg/L in the monitoring well. The concentration dropped to 50 μg/L after 8 days and to 1.5 μg/L after 35 days. In addition, test results showed that tertiary compounds were not generated. To further alleviate LEA's concerns with this innovative remedial process operation, the pilot test protocol included deployment of a down-hole video camera, in combination with dissolved oxygen meter results, to record the intercept on the monitoring well from the local sparge point locations. Contaminant concentrations in downgradient wells have shown further improvement, and the system continues to protect the muni well.

The subject site, a retail gasoline station in California's Central Valley, originally received a "no further action" resolution in 1996, but GRO and MTBE compounds were confirmed present in groundwater samples taken during Phases I and II investigations conducted in 2003, after new underground storage tanks (USTs) were installed. Results showed both soil and groundwater contamination. In December 2004, groundwater data revealed a relatively large groundwater plume of GRO compounds, including MTBE. Concentrations have ranged as high as 33,000 μg/L of GRO (by Method SW8015 [Mod.]) and 30,000 μg/L of MTBE (by Method SW8260B) in samples collected from monitoring well MW-11. These analytes were acknowledged to be a threat to groundwater drinking water supplies, because the plume was migrating off site toward a city municipal water supply well. The muni well is located approximately 120 feet to the southeast of the gas station property, and protection of this well was of paramount importance. To achieve muni well protection and control off-site migration of the plume, various remedial technologies were evaluated. An air/ozone sparge curtain was selected to contain the plume and reduce the threat.

2. BACKGROUND

The site is located at a busy intersection in a California Central Valley town (Figure 1). The northern portion of the site is an operating gasoline station and mini-mart. Property facilities include three gasoline USTs and associated product lines and dispensers. To the south is a car rental agency. Both properties are relatively flat, mostly paved, and have a surface elevation of approximately 90 feet above mean sea level. An operating muni well is located approximately 120 feet to the southeast of the gasoline station property, near the southeast corner of the car rental agency property.

Investigation of this site was initiated in 1990 when a leak was discovered in the product line located between the north pump island and the building. Since then, many well installation efforts have taken place to define the plume's extent. Figure 2 is a site map locating all of the installed monitoring wells and vapor extraction wells, and the air/ozone sparge locations.

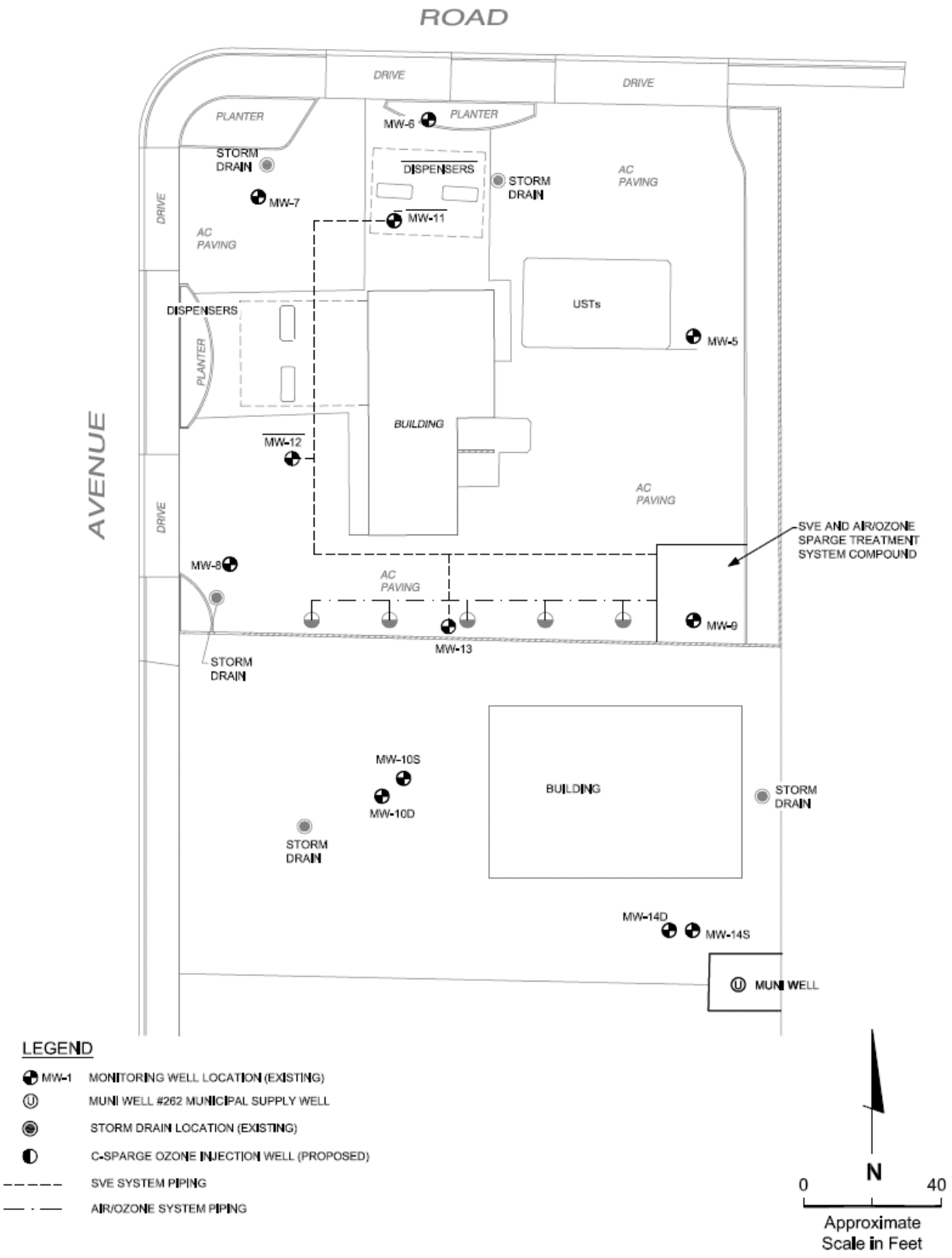

Figure 1. Site Plan

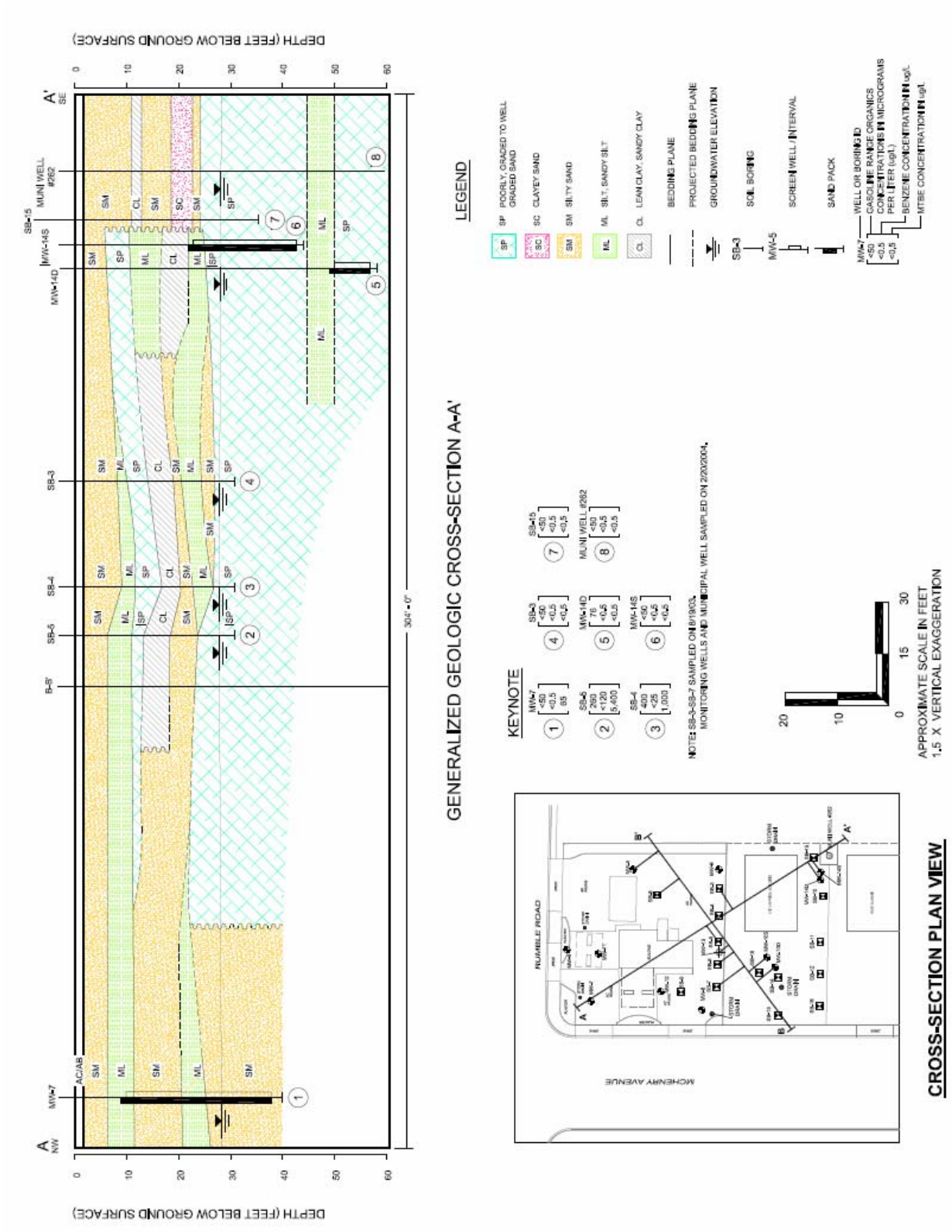

Figure 2. Generalized Geologic Cross-Section A-A'

2.1 Site Geology and Hydrogeology

Soils encountered during drilling activities consist of highly interbedded, poorly graded sand, clayey sand, silty sand, sandy silt, silt, sandy clay, and lean clay. A large clay lens exists from

approximately 12 to 16 feet bgs, and a bed of hard silt exists from approximately 45 to 49 feet bgs. Generalized geologic cross-sections are presented as Figures 3 and 4.

During past drilling activities, first water was encountered in poorly graded sand (between 27.5 and 29 feet bgs) that constitutes the surface of a shallow water-bearing zone. A deeper water-bearing zone was encountered at 49 feet bgs. Based on observations of historical quarterly groundwater monitoring data, the inferred direction of groundwater flow at the site ranges from the southwest to the south, at an average hydraulic gradient of 0.0002 to 0.001 feet per foot, toward the municipal supply well.

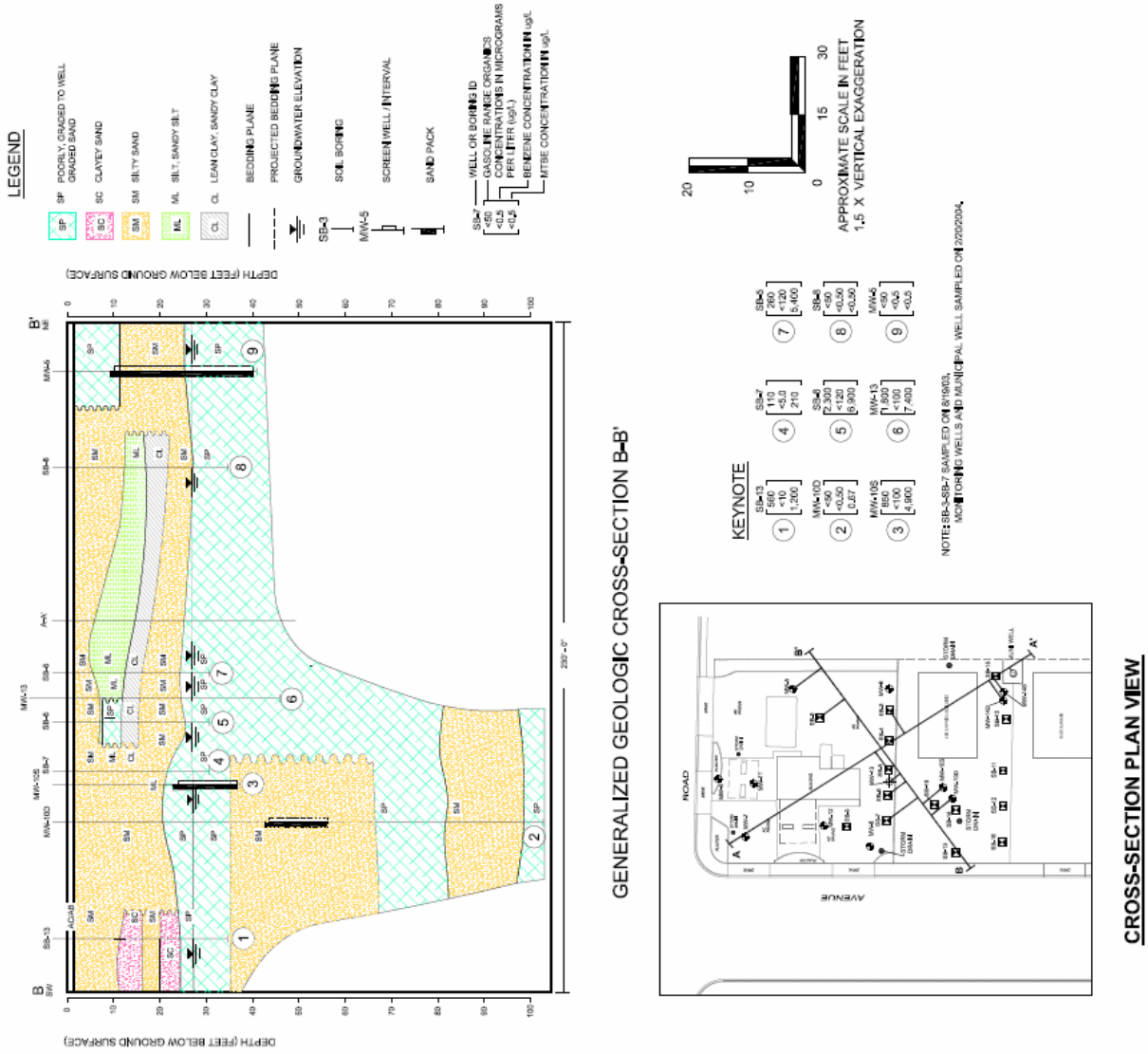

Figure 3. Generalized Geologic Cross-Section B-B'

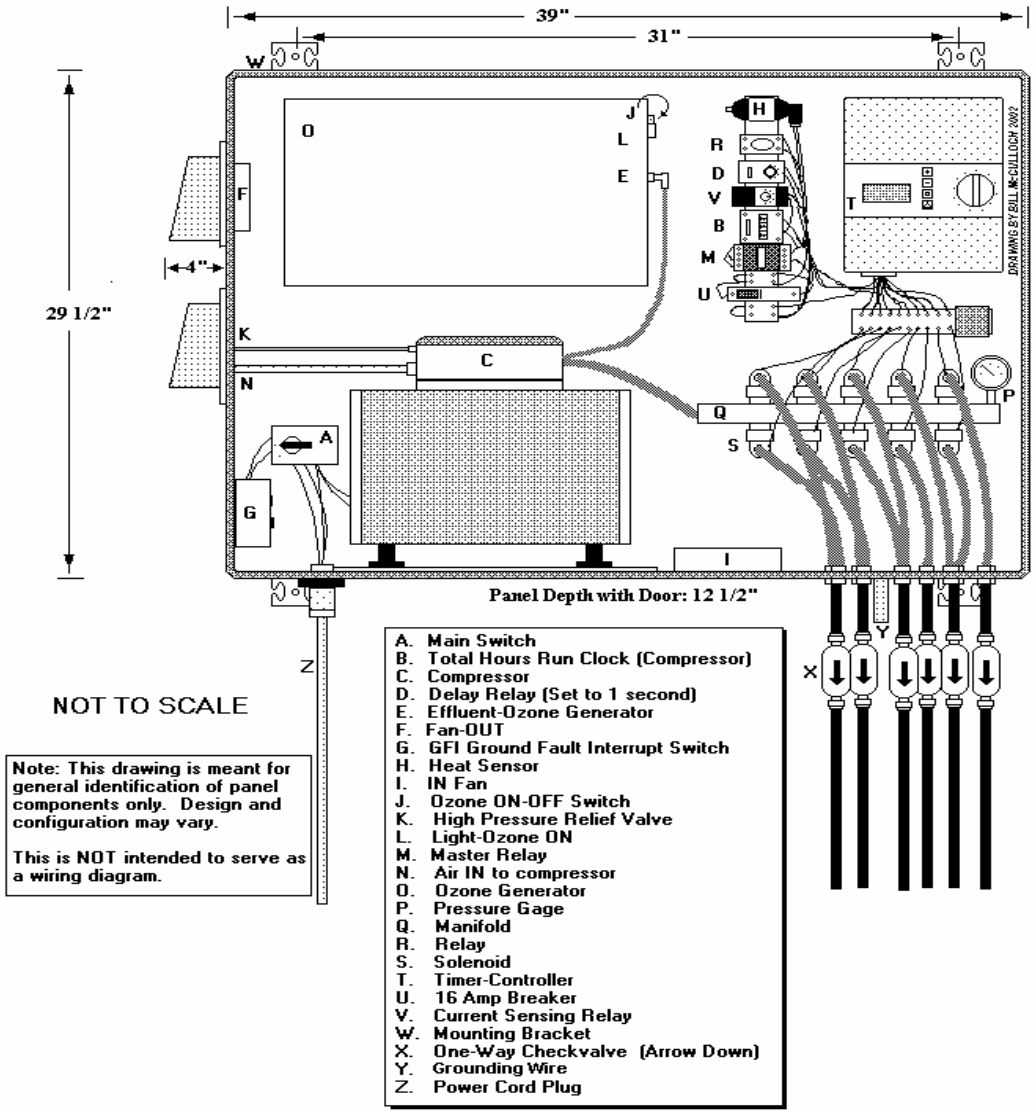

Figure 4a. The Air/Ozone KVA C-Sparger Panel. Schematic

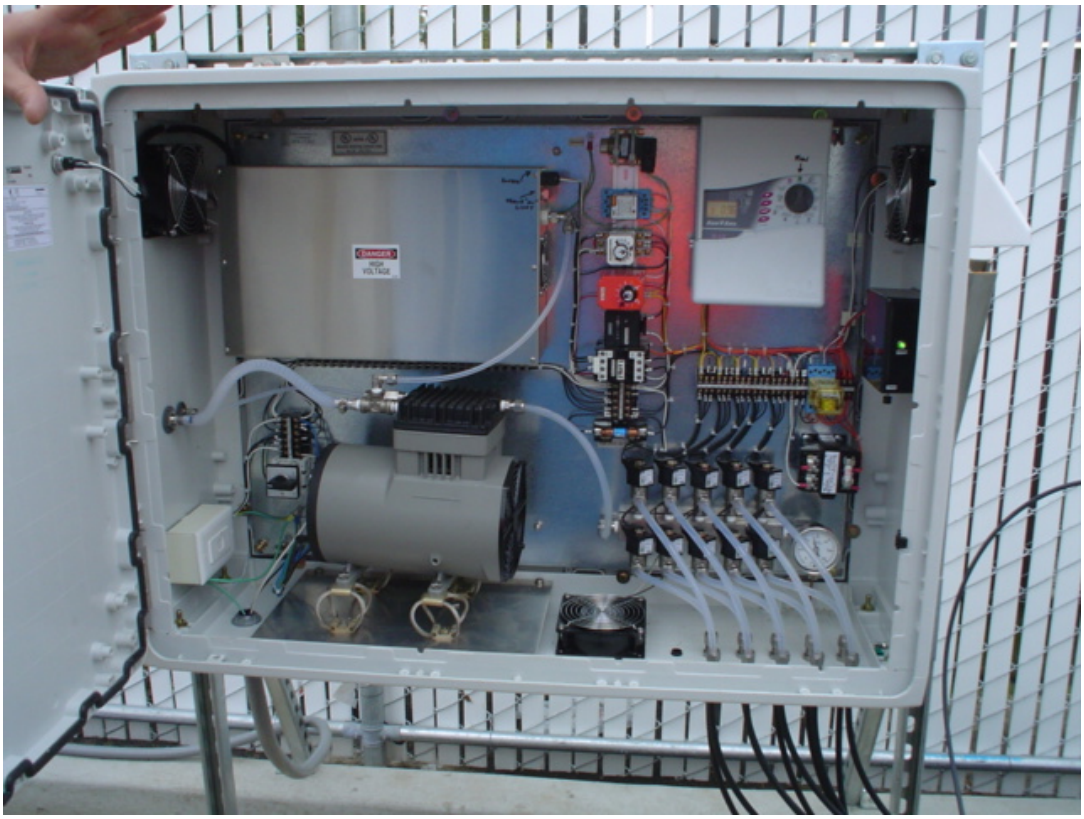

Figure 4b. The Air/Ozone KVA C-Sparger Panel. Field Application at Site 2063. The Panel is about 2' by 3' by 1'

3. REMEDIAL OBJECTIVES

Site remedial objectives were to (1) protect the existing municipal water supply well from a rapidly approaching plume from the site operation; (2) implement a remediation process that would not require pumping with topside treatment and discharge, since discharge to the local sewer was not available, according to the sewer district; and (3) implement a remediation process that is proven, readily implementable, efficient, and cost-effective. The approach URS used was to consider innovative *in situ* process operations that would be effective in the subsurface hydrogeologic conditions of California's Central Valley. Since this project was time-critical, URS relied heavily upon the hands-on experience of the remediation engineers.

3.1 Remediation Technologies Evaluation and Selection

Because soil and groundwater were contaminated, both media needed to be addressed. An estimated 3,500 pounds of GROs remained in soils. An estimated 13 pounds of GRO and 35 pounds of MTBE were present in the groundwater. For the vadose zone source area, two alternatives were evaluated: excavation with off-site disposal and SVE. Remedial alternatives considered for groundwater were groundwater pump-and-treat with off-site disposal, *in situ* chemical oxidation (air/ozone sparging), containment, air sparging, and monitored natural attenuation.

The technology alternatives were selected with due consideration to the immediate need to remediate petroleum-impacted soil and groundwater, to prevent migration of contaminants to the muni well. The final recommendation submitted in the Corrective Action Plan (CAP) was to implement SVE for soil remediation in conjunction with air/ozone sparging for groundwater remediation.

4. AIR/OZONE SPARGE SYSTEM DESIGN

The selected system is a panel-mounted air/ozone sparge system provided by McCulloch Equipment and manufactured by Kerfoot Technologies (2006). This section details the air/ozone sparging process, the sparge curtain, and the air/ozone sparge system supplied by Kerfoot Technologies.

4.1 Air/Ozone Sparge Process

Air/ozone sparging is the injection of ambient air with ozone into the saturated zone (below the groundwater table) to destroy contaminants *in situ*. Ozone is generated on site from ambient air using a method called corona discharge. In corona discharge, an electrical charge splits an oxygen molecule into two oxygen atoms. The resulting unstable oxygen atoms combine with other oxygen molecules to form ozone (O_3). From the corona discharge ozone generator, the air/ozone mixture is compressed for injection into the saturated zone. Once released into the aquifer, it oxidizes (destroys) contaminants *in situ*. Ozone is unstable and has a very high oxidizing potential; therefore, it will oxidize contaminants very rapidly then return to the more stable oxygen molecule. Any excess ozone will degrade back to the oxygen molecule in a relatively short time. Ozone's half-life in the presence of water is typically 30 minutes at standard temperatures and pressures. Because ozone is a gas, it can also be used for vadose zone remediation. However, this is not the intent at this site because of the installed SVE system. As a secondary effect, as the ozone degrades back to oxygen it can help stimulate aerobic biodegradation.

4.2 Air/Ozone Sparge Curtain

To best implement the air/ozone sparging technology and to protect the downgradient muni well, a sparge curtain was installed. As previously discussed, Figure 2 depicts the sparge curtain layout and its location on the gas station property. The sparge curtain was sited between the source area and the municipal well. By sparging in this fashion, the sparge points are still located on the service station property while also reducing the contaminant concentrations moving downgradient, as demonstrated in the historical analytical data. The curtain is composed of five wells located slightly less than 30 feet from each other. Each well is intended to have a radius of influence (ROI) of 15 feet, and contains one deep and one shallow sparge location—for a system total of 10 discrete sparge locations. Air/ozone sparge wells AOS-1 through AOS-10 were completed in their respective 8-inch diameter boreholes under the direction of a URS geologist. The wells were constructed using 0.75-inch inside-diameter (ID), Schedule 40, flush-threaded polyvinyl chloride (PVC) well casing. The 2-inch by 30-inch sparge points were installed on separate PVC casings, as follows:

Shallow sparge points were installed from 32 to 39.5 feet bgs.
Deep sparge points were installed from 42.5 to 50 feet bgs.

Sand filter packs were installed from the bottom of the borings to 2.5 above the deepest sparge points, and from 6 inches below the shallow sparge points to 2.5 feet above. Bentonite seals were placed between the deep and shallow sand packs and a 3-foot bentonite transition seal was placed in the annular space above the shallow sand packs. Neat cement grout was used to seal the remaining annular space to 1 foot bgs. The wells were completed with traffic-rated, flush-mounted, well vaults.

4.3 Air/Ozone Sparge System Components

The air/ozone sparging process used at the site has been developed by Kerfoot Technologies, and is called C-Sparge™ (as illustrated on Figure 5). This technology injects micro bubbles (approximately 50 μm in diameter) of encapsulated ozone directly into the groundwater. The micro bubbles are randomly dispersed through the water and the saturated soil formation. The process

combines stripping and treatment, targeting both soil (any contaminants sorbed to soil particles) and groundwater (dissolved-phase contaminants). The encapsulated ozone reacts with the contaminants, producing harmless byproducts such as water, carbon dioxide, and oxygen. The injection concentration and mass loading are low with this system, typically between 80 to 350 parts per million by volume (ppmv) and less than 1 pound per day, respectively. The air/ozone mixture injection is pulsed; the pulse frequency and duration are controlled by a timer located in the panel-mounted system, and optimized as contaminant concentrations are reduced.

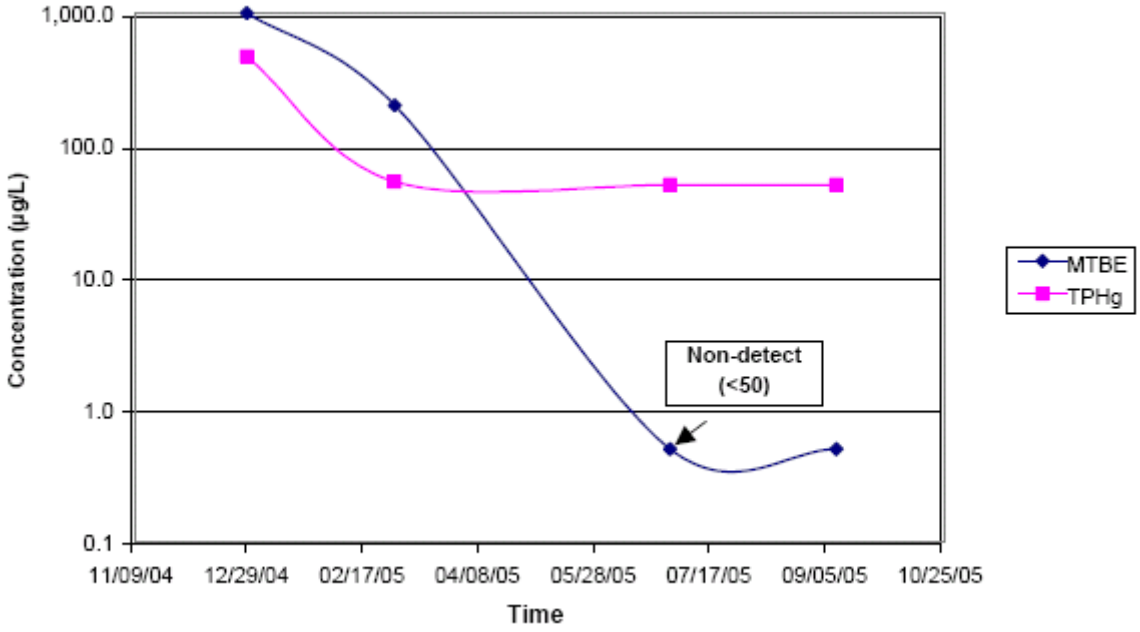

Figure 5. MW-10S Concentration (µg/L) vs. Time

5. AIR/OZONE DESIGN SPECIFICS

Once URS proposed installing the *in situ* air/ozone sparge process, the Lead Enforcement Agency (LEA) requested a pilot test work plan and more information on the innovative process operation, since they suspected it could generate deleterious secondary compounds. URS (2004) agreed to conduct a pilot test designed to satisfy the LEA's directives and comments. Pilot test activities included soil sample collection to analyze for content of a specified list of elements from soil, groundwater sample collection and analysis to determine whether deleterious secondary compounds could be generated as the result of sparging, and assessment of system efficiency for remediation of gasoline-related hydrocarbons.

5.1 Stoichiometry, or Chemical Equations

Design Request: Provide stoichiometry or chemical equations for the reaction between the soil and groundwater and the injected ozone.

In general terms, the chemical oxidation of petroleum compounds ultimately breaks the targeted organic compound down into carbon dioxide and water.

For hydrocarbons, the generalized stoichiometry equation is:

$$H_2O + HC + O_2 + O_3 \longrightarrow CO_2 + H_2O$$

Where "HC" designates petroleum compounds (i.e., hydrocarbons).

Ideally, the generalized stoichiometry equation for the complete oxidation of MTBE is:

$$C_5H_{12}O + 5O_3 \longrightarrow 5CO_2 + 6H_2O$$

5.2 Soils Testing

Design Request: Provide results of a leachability testing of native soils, to determine the potential effects from the ozone injection. General mineral analyses should be conducted to evaluate if naturally occurring minerals will move into solution as a result of the ozone injection. The following general mineral suite should be evaluated: aluminum, antimony, arsenic, barium, beryllium, cadmium, calcium, chromium (III and VI), cobalt, copper, iron, lead, magnesium, manganese, mercury, molybdenum, nickel, potassium, selenium, silver, sodium, thallium, tungsten, vanadium, and zinc.

URS clarified the requests in the Stanislaus County Department of Environmental Resources (SCDER) letter, dated July 16 2004, in regard to item "2B soil leachability testing." URS communicated with the Regional Water Quality Control Board, Central Valley Region (RWQCB-CVR) on August 3, 2004 and the SCDER on August 4, 2004. URS, RWQCB-CVR, and SCDER agreed that requests made in Item 2B of the SCDER letter would be satisfied by conducting analyses of specified mineral/element content for soil samples to be collected during air/ozone sparge point installation.

As the sparge point borings were drilled, at least three soil samples were collected for the analyses requested, as follows:

General elements/minerals referenced in the SCDER letter dated July 2004, include metals by the United States Environmental Protection Agency (EPA) Method 200.7/7471A, chromium (IV) by EPA Method 7199, general anions by EPA Method 300.0, and -log $[H^+]$ (pH) by EPA Method 9045.

5.3 Groundwater Sampling and Analyses

Design Request: Provide results of general mineral analyses of the groundwater. Results from this analysis should be used to evaluate if naturally occurring minerals will precipitate out of the groundwater as a result of the ozone injection. The following general mineral suite should be evaluated: aluminum, antimony, arsenic, barium, beryllium, cadmium, calcium, chromium (III and VI), cobalt, copper, iron, lead, magnesium, manganese, mercury, molybdenum, nickel, potassium, selenium, silver, sodium, thallium, tungsten, vanadium, and zinc.

Groundwater samples were collected at three intervals for the pilot test including, *Time Zero* – prior to the air/ozone sparge testing, *Time 4 Hours* – after the air/ozone sparge test has been initiated and *Time Day 3* – after the air/ozone sparge test has been initiated (assuming that no deleterious compounds were reported from the *Time 4 Hours* test result).

The groundwater was analyzed for electrical conductivity (EC), total dissolved solids (TDS) and pH, using a calibrated handheld meter:

Groundwater samples were analyzed for the general elements referenced in the SCDER letter dated July 2004, including: metals (including mercury) by EPA Method 200.7/7470A, chromium (IV) will be analyzed by EPA Method 7199, general anions will be analyzed by EPA Method 300.0.

The generation of deleterious secondary compounds is not anticipated.

5.4 Estimate the Mass of Constituents Released to the Aquifer

Design Request: Provide an estimate of the mass of other constituents/parameters, including Electrical Conductivity (EC), chlorides, sulfides, etc. which will be released into the aquifer as a result of the ozone injection, and the rationale for the estimate.

Any measurable amounts or significant difference in the pre-air/ozone sparging versus post-air/ozone sparging concentrations for the EC, chlorides, or sulfates were not anticipated and did not appear.

5.5 Estimate the Mass of TDS

Design Request:Provide an estimate of the mass of TDS that will be mobilized by the injection of the ozone, and the rationale for the estimate.

Any measurable amounts or significant difference in the pre-air/ozone sparging versus post-air/ozone sparging concentrations for TDS was not anticipated and did not appear.

5.6 Estimate Changes in pH

Design Request:Provide estimates of changes in pH in groundwater and the radius of influence for the proposed ozone injection.

Any measurable amounts or significant difference in the pre-air/ozone sparging versus post-air/ozone sparging concentrations for pH was not anticipated and did not appear. The minimum estimated ROI is 20 feet.

5.7 Assess Site-Specific Effectiveness for Air/Ozone Sparging

Design Request: Provide an assessment of the site specific effectiveness of ozone sparging for eliminating identified soil and groundwater contamination in this case, and identify/demonstrate that any breakdown products of this process (e.g., acetone and/or degradation products) are analyzed for and addressed by the planned remediation.

Pilot Test details are presented below, under Pilot Test Procedure. In summary, during sparger installation, soil samples from the vadose zone and saturated zone were collected for analysis. Groundwater samples were obtained and sent for analyses at *Time Zero*, before the air/ozone sparge test; *Time 4 Hours* – during the air/ozone sparge test, and *Time, Day 3* – during the air/ozone sparge test.

The specific effectiveness of the air/ozone sparging was presented in a letter report to the SCDER and RWQCB for review and comment. URS' previous experience with this technology, along with the pilot test results, demonstrated dramatic positive effects on subsurface gasoline-related hydrocarbon reductions.

6. PILOT TEST PROCEDURE

The pilot scale test procedure was developed using the guidelines provided in the SCDER letter dated July 16, 2004. It was conducted under the supervision of a URS licensed Professional Engineer and a URS Geologist. The letter required that sites with *in situ* air/ozone sparging as the recommended remedial process be tested with a full-scale pilot test in lieu of a lab bench-scale test procedure. This test procedure assessed whether the recommended remediation process altered the aquifer water chemistry or generated deleterious secondary compounds during the oxidation process.

The pilot test activities included background groundwater sampling and analyses, installation of all air/ozone sparge equipment and start-up of the air/ozone sparge equipment. The field test was conducted as described below:

Pre-sparge water samples were collected and analyzed in accordance with the analyses specified; additionally, URS tested a water sample for EC, TDS and pH, using a calibrated handheld meter.

Air/ozone sparging was initiated at the lower sparge location in SW-2B for two hours.

A downhole video camera was employed in MW-13 to assess and record the location and interception of the air/ozone bubbles at the well screen. The location of the bubble flux intercept was recorded such that the phi angle and radius of influence were calculated and recorded.

Initiated air/ozone sparging at the upper sparge location in SW-2 (SW-2A) for two hours.

Deployed downhole video camera in well MW-13 to assess and record the location and interception of the air/ozone bubbles at the well screen. The location of the bubble flux intercept was recorded such that the phi angle and radius of influence were calculated and recorded.

When the air/ozone sparge system operated for a total of four hours,URS obtained a groundwater sample from MW-13; the water sample was analyzed according to the analyses specified previously; additionally, URS tested a water sample for EC, TDS, and pH with a calibrated handheld meter.

Initiated air/ozone sparging at the lower sparge location in SW-3 (SW-3B) for two hours.

Deployed downhole video camera in MW-13 to assess and record the location and interception of the air/ozone bubbles at the well screen. The location of the bubble flux intercept was recorded such that the phi angle and radius of influence was calculated and recorded.

URS decided not to utilize the camera on other monitoring wells in the immediate vicinity since the sparge bubbles could be seen clearly.

The *four-hour groundwater sample results* were reviewed as soon as practical for compounds that may have been inadvertently generated during the initial four-hour sparging activity. These results showed that no deleterious compounds were produced.

Initiated air/ozone sparging at the upper sparge location in SW-3 (SW-3A) for two hours.

Deployed downhole video camera in MW-13 to assess and record the location and interception of the air/ozone bubbles at the well screen. The location of the bubble flux intercept was recorded such that the phi angle and radius of influence was calculated and recorded.

The groundwater results did not show that deleterious compounds were generated as a result of the air/ozone system.

The air/ozone sparge system operated for an additional three days. URS obtained a groundwater sample from MW-13; the water sample was analyzed in accordance with the analyses specified in C above; additionally, URS tested a water sample for EC, TDS, and pH with a calibrated handheld meter.

Continued the air/ozone sparging at the four locations on a cyclical basis in SW 2A, SW-2B, SW-3A, and SW-3B for equal time periods.

The three-day groundwater sample results were reviewed as soon as practical for compounds that may have been inadvertently generated during the initial three-day sparging activity. These results did not show that generation of deleterious compounds were generated as a result of the sparging activities.

7. REMEDIATION SYSTEM RESULTS AND CONCLUSIONS

The SVE system was operated between December 2004 and March 2006, slightly more than 14 months, then shut down for rebound testing. Ozone treatment took place between February 2005 and September 2005, a total of about seven months. Groundwater sampling results are presented in Table 1. Figures 5, 6 and 7 graph MTBE and TPHg, show concentration time at three select monitoring wells. Figures 8, 9 and 10 are plume maps showing the aerial extent of MTBE and TPHg concentrations in groundwater. Both the data and the figures illustrate the dramatic reduction in MTBE and TPHg concentrations resulting from system operation, and verify the lack of rebound of either contaminant.

Table 1. Complete Analytical Results For TPH-g and MTBE

Well Number	Date Sampled	TPH-g [µg/L]	MTBE [µg/L]	Hexavalent Chromium [µg/L]
Muni Well	12/27/2004	--	--	--
	01/10/2005	<50	<0.50	--
	02/11/2005	<50	<0.50	--
	03/01/2005	<50	<0.50	--
	04/06/2005	<50	<0.50	--
	04/20/2005	<50	<0.50	--
	06/28/2005	<50	<0.50	--
	07/21/2005	--	--	--
	08/01/2005	<50	<0.50	--
	09/08/2005	<50	<0.50	--
	09/22/2005	--	--	3.4
	12/21/2006	<50	<0.50	1

Well Number	Date Sampled	TPH-g [µg/L]	MTBE [µg/L]	Hexavalent Chromium [µg/L]
	3/21/2006	<50	<0.50	<0.50
	6/20/2006	<50	<0.50	5.3
MW-5	12/27/2004	<50	<0.50	--
	03/01/2005	<50	<0.50	--
	06/28/2005	<50	<0.50	--
	09/08/2005	<50	<0.50	--
	09/22/2005	--	--	5.2
	12/21/2006	<50	<0.50	--
	3/21/2006	<50	<0.50	--
	6/20/2006	<50	<0.50	--
MW-6	12/27/2004	<50	<0.50	--
	03/01/2005	<50	<0.50	--
	06/28/2005	<50	<0.50	--
	09/08/2005	<50	<0.50	--
	12/21/2006	<50	<0.50	--
	3/21/2006	<50	<0.50	--
	6/20/2006	<50	<0.50	--
MW-7	12/27/2004	<50	39	--
	03/01/2005	<50	23	--
	06/28/2005	<50	<0.50	--
	09/08/2005	<50	<0.50	--
	12/21/2006	<50	13	--
	3/21/2006	<50	<0.50	--
	6/20/2006	<50	<0.50	--
MW-8	12/27/2004	<50	1.0	--
	03/01/2005	<50	<0.50	--
	06/28/2005	<50	<0.50	--
	09/08/2005	<50	<0.50	--
	12/21/2006	<50	<0.50	--
	3/21/2006	<50	<0.50	--
	6/20/2006	<50	<0.50	--
MW-9	12/27/2004	<50	<0.50	--
	01/31/2005	--	--	2.5
	03/01/2005	<50	<0.50	--
	06/28/2005	<50	<0.50	--
	09/08/2005	<50	<0.50	1.8
	09/22/2005	--	--	2.9
	12/21/2006	<50	<0.50	0.77
	3/21/2006	<50	<0.50	1.1
	6/20/2006	<50	<0.50	1.2
MW-10D	12/27/2004	<50	0.67	--
	03/01/2005	<50	0.65	--
	06/28/2005	<50	<0.50	--
	09/08/2005	<50	<0.50	45*
	09/22/2005	--	--	9.7
	12/21/2006	<50	<0.50	5
	3/21/2006	<50	<0.50	15
	6/20/2006	<50	<0.50	17
MW-10S	12/27/2004	470	1,000	--
	03/01/2005	53	200	--
	06/28/2005	<50	<0.50	--
	09/08/2005	<50	<0.50	1.1
	09/22/2005	--	--	1.1
	12/21/2006	<50	<0.50	5.2
	3/21/2006	<50	<0.50	0.9
	6/20/2006	<50	<0.50	4
MW-11	12/27/2004	33,000	30,000	--
	03/01/2005	590	190	--
	06/28/2005	170	49	--

Well Number	Date Sampled	TPH-g [µg/L]	MTBE [µg/L]	Hexavalent Chromium [µg/L]
	09/08/2005	<500	340	<0.50
	09/22/2005	--	--	<0.50
	12/21/2006	<50	40	<0.50
	3/21/2006	<50	3.2	<0.50
	6/20/2006	<50	9.9	<0.50
MW-12	12/27/2004	50	23	--
	03/01/2005	660	400	--
	06/28/2005	110	6.1	--
	09/08/2005	180	7.6	--
	12/21/2006	<50	1.7	--
	3/21/2006	<50	1.5	--
	6/20/2006	<50	1.5	--
MW-13	12/27/2004	490	970	--
	01/31/2005	--	--	0.80
	03/01/2005	<50	1.5	--
	06/28/2005	<50	<0.50	--
	09/08/2005	<50	<0.50	4.0
	09/22/2005	--	--	4.6
	12/21/2006	<50	<0.50	0.97
	3/21/2006	<50	<0.50	<0.50
	6/20/2006	<50	<0.50	<0.50
MW-14D	12/27/2004	<50	<0.50	--
	01/10/2005	<50	<0.50	--
	02/11/2005	<50	<0.50	--
	03/01/2005	<50	<0.50	--
	04/06/2005	<50	<0.50	--
	04/20/2005	<50	<0.50	--
	06/28/2005	<50	<0.50	--
	07/21/2005	<50	<0.50	--
	08/01/2005	<50	<0.50	--
	09/08/2005	<50	<0.50	--
	09/22/2005	--	--	1.3
	12/21/2006	<50	<0.50	<0.50
	3/21/2006	<50	<0.50	0.92
	6/20/2006	<50	<0.50	1.7
MW-14S	12/27/2004	<50	<0.50	--
	01/10/2005	<50	<0.50	--
	02/11/2005	<50	<0.50	--
	03/01/2005	<50	<0.50	--
	04/06/2005	<50	<0.50	--
	04/20/2005	<50	<0.50	--
	06/28/2005	<50	0.62	--
	07/21/2005	<50	0.70	--
	08/01/2005	<50	<0.50	--
	09/08/2005	<50	<0.50	--
	09/22/2005	--	--	3.5
	12/21/2006	<50	<0.50	1.5
	3/21/2006	<50	<0.50	0.5

Notes: * Result did not confirm upon resampling

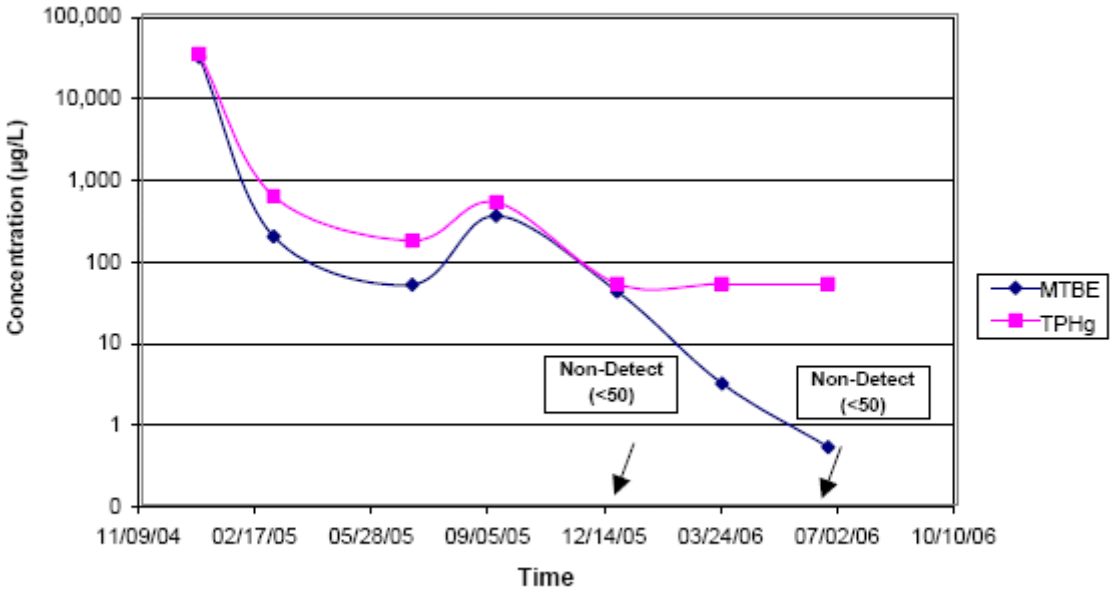

Figure 6. MW-11 (Source Area) Concentration (µg/L) vs. Time. (Note: TPHg data was non-detect, <500 but not included because of high reporting limit)

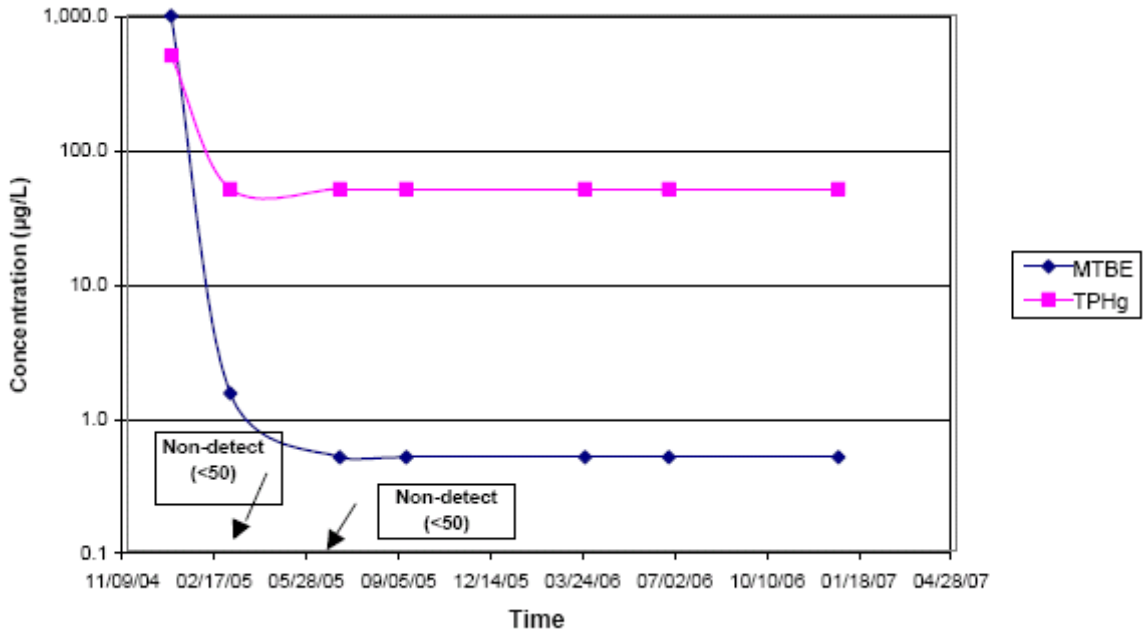

Figure 7. MW-13 (Near Sparge Curtain) Concentration (µg/L) vs. Time

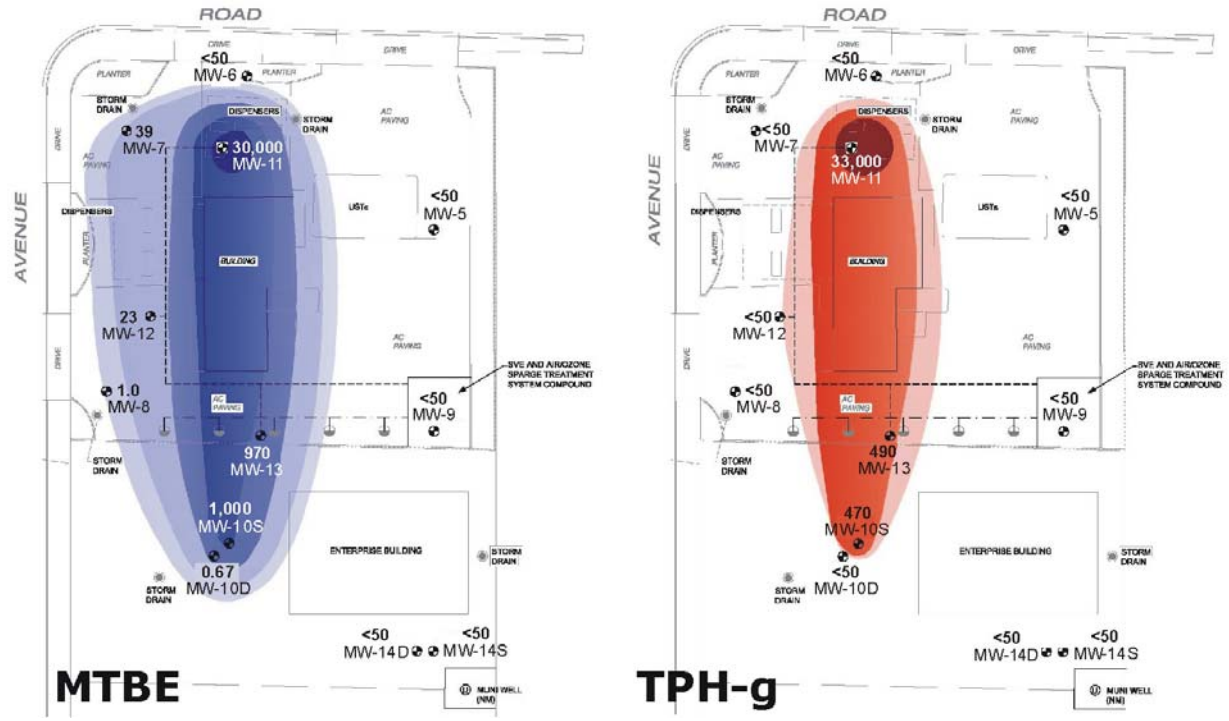

Figure 8. 30 Days before Remediation Startup, December 2004. MTBE in Groundwater (µg/L) and TPH-g in Groundwater (µg/L)

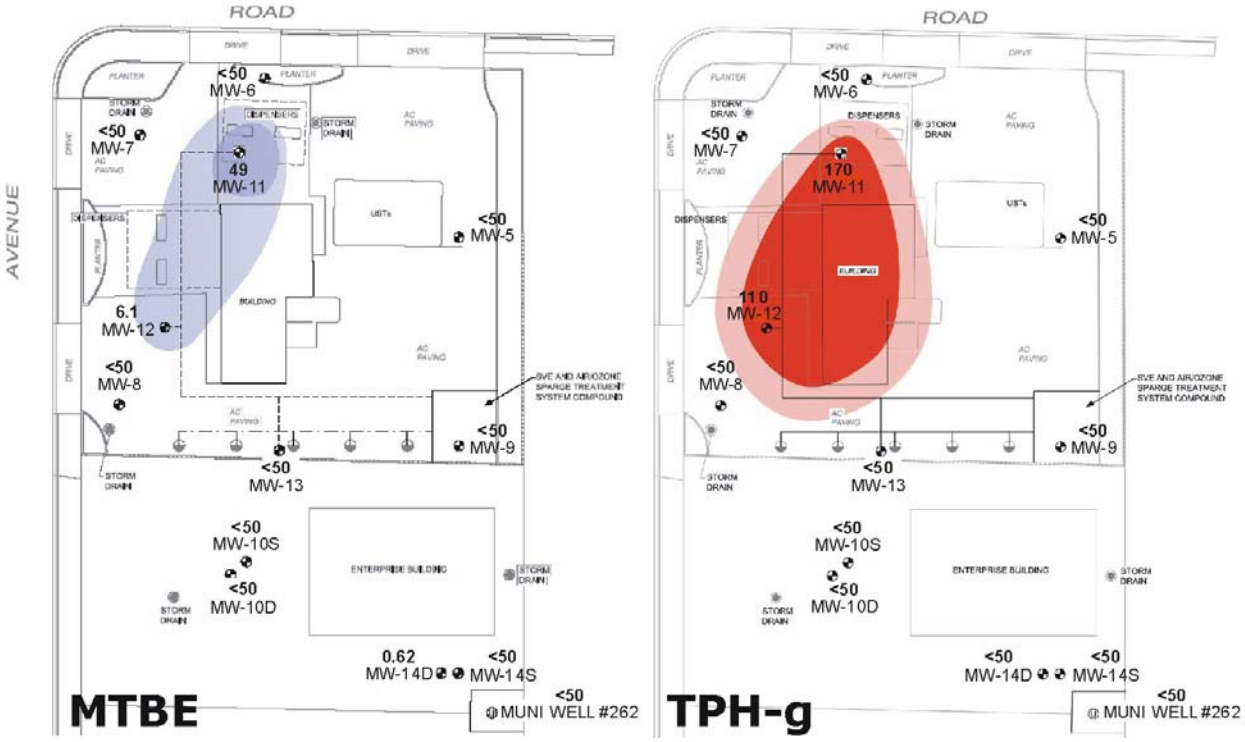

Figure 9. After 150 Days Operating, June 2005. MTBE in Groundwater (µg/L) and TPH-g in Groundwater (µg/L)

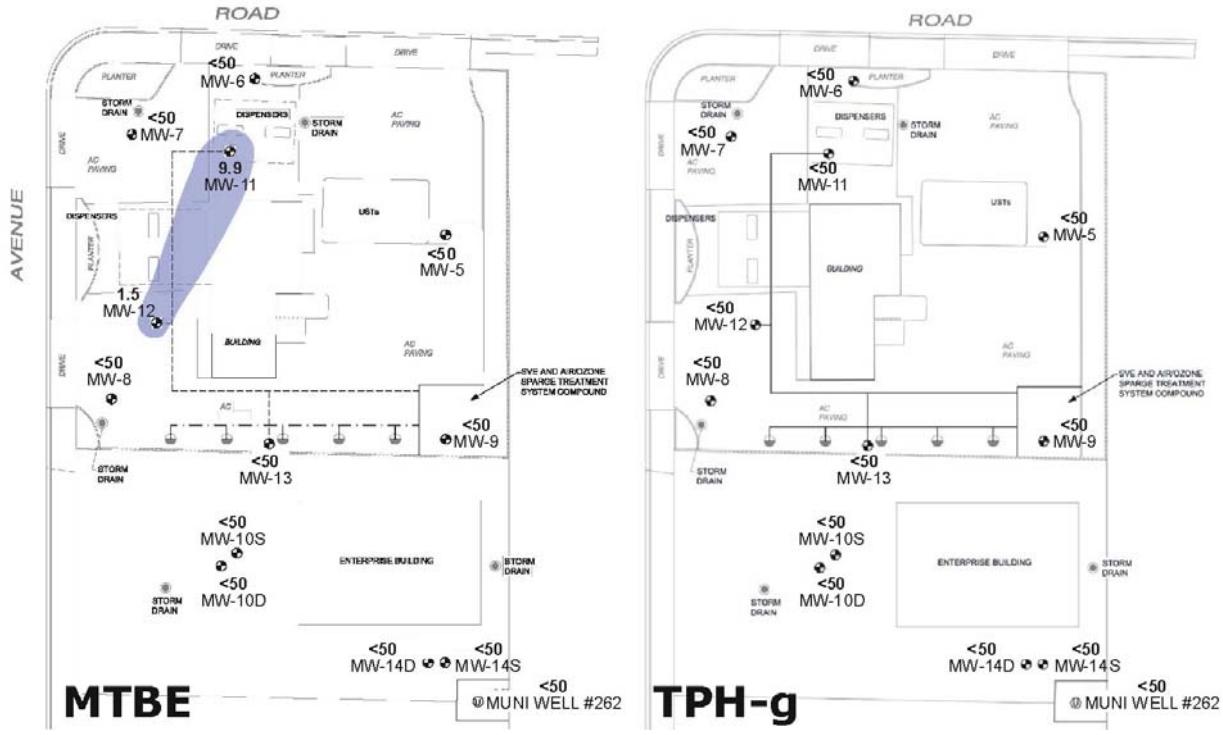

Figure 10. After 17 Months Operating, June 2006. MTBE in Groundwater (µg/L) and TPH-g in Groundwater (µg/L)

In summary, URS has concluded the following:

The air/ozone sparge curtain worked effectively and afforded excellent protection to the municipal supply well.

The groundwater monitoring well results show that the aquifer has some small concentrations of total chromium and hexavalent chromium as indicated in the upgradient monitoring well and pre-system operation results. These total chromium and hexavalent chromium results are considered naturally occurring and represent background conditions.

The current MTBE and TPHg concentrations are non-detectable (ND) based on a laboratory reporting limit of 0.5 µg/L for MTBE and 50 µg/L for TPHg in the immediate vicinity of the sparge curtain and 90 feet upgradient to MW-11 and 100 feet downgradient to MW-14D and MW-14S. Based on these results, site closure is expected following further monitoring.

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